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Full Length Research Paper

Mercury bioaccumulation in sediment and root of mangrove forest, *Avicennia marina* from Emam Khomein Port, north part of the Persian Gulf

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In this study, the mercury distribution in sediment and bioaccumulation in root of mangrove forest, *Avicennia marina* from Emam Khomeini Port, located in Khuzestan province south Iran and head of the Persian Gulf were studied. For this analyses, sediment and mangrove samples were collected from four sampling sites including Petrochemical, Majideih, Jafari and Majideih were. After preparation, the concentration of every metal was measured using the ICP-AES. The mean concentration of mercury in different sampling sites in summer were 1.69 ± 1.45 µg/g in site 1, 0.86 ± 0.05 µg/g in site 2, 0.60 ± 1.23 µg/g in site 3 and 0.16 ± 2.19 µg/g in sites 4, and also in winter were 2.34 ± 0.49 µg/g in site 1.10 ± 5.27 µg/g in site 2, 0.66 ± 0.25 µg/g in site 3 and 0.17 ± 131 µg/g in sites 4, respectively. The mean concentration of mercury in root of mangrove forest, *A. marina* in summer season were 3.26 ± 3.16 in site 1, 1.49 ± 0.75 in site 2, 0.87 ± 2.61 in site 3 and 0.65 ± 4.05, and also in winter were 4.13 ± 4.35 in site 1, 1.93 ± 2.31 in site 2, 0.94 ± 1.56 in site 3 and 0.67 ± 0.24 in site 4. There was significant differences in mercury value in sediments and root of *A. marina* between diffident sampling sites and seasons ($P<0.05$), and mercury value in all sampling sites were as Petrochemical > Majideih > Jafari > Bardestan. Also, there was significant differences between diffident seasons ($P<0.05$) and higher mercury was absorbing in winter. The results showed that *A. marina* is one a plant that can be absorbing mercury from around sediments and transportation to other tissues, therefore, could be removal mercury from aquatic ecosystem in Emam Khomeini Port, north part of the Persian Gulf. In general, phytoremediation is a new and best technology for removal of metal from aquatic ecosystems, and *A. marina* is important species in different coasts of the Persian Gulf, therefore, this species can using for removal and purgation of mercury from different coasts of Persian Gulf.

Keywords: Mercury, Bioaccumulation, Mangrove Forest, *Avicennia marina*, Emam Khomein Port

INTRODUCTION

Mercury is a toxic heavy metal which cycles through atmosphere, water, and soil in various forms to different parts of the world. Mercury release occurs by both natural and anthropogenic processes (Al Anouti, 2014). Mercury can enter to the coasts and marine environment by

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different anthropogenic sources such as oil and petrochemicals industries, refinery, agriculture industry and also urban and Industrial wastewater (Chih-Yu and Chang-Hung, 1991; Al Hagibi et al. 2018). Mercury can get bio-accumulated in marine food chains in the form of highly toxic methyl mercury which can cause health risks to human seafood consumers. According to statistics, about 66% of the global fish consumption comes from ocean. Therefore, it is important to monitor and regulate oceanic mercury levels to prevent more and more mercury reaching human population through seafood consumption (Cyril Marchand et al. 2006; Almahasheer et al. 2014).

Determination of metal distribution in core sediments can provide valuable information about the current and background levels of contamination and may provide historical evidence of the anthropogenic effect in the aquatic environment. Such sediment core studies of various elements have been shown to track natural background concentrations and anthropogenic activities through deviations from a background (Ding et al. 2011; Debargha et al. 2013). The difference in heavy metal concentration in the marine environment can be caused by industry, domestic sewage, boating activities, mining, and refining. The distribution of mercury in the aquatic environments is positively correlated to population density and urbanization via the large uncontrolled input from industrial activates. Mercury is able to accumulate in marine sediments and may affect human health through the food chain via benthic organisms (Dias et al. 2016; Dung Quang et al. 2017).

Coastal and marine environments are potentially at risk due to a high concentration of mercury in sediments and organisms. Mangrove plants comprise a group of intertidal plants that dominate the coastlines of many tropical and subtropical regions, and they are highly productive and play a vital role as the major primary producers in estuarine ecosystems (Debargha et al. 2013). As the mangrove forest sediments have a high potential for storing heavy metals from the water in tropical and subtropical regions. The high capability of mangrove to absorb and store heavy metals in its sediments, is because of the physicochemical properties of these sediments. Therefore, the mangrove forest sediments are a good indicator of heavy metal concentration, and they can transfer the pollutions to the mangrove tissues (Edul et alk. 2015).

Avicennia marina is one of the important species of mangrove forest in the different coasts of the Persian Gulf. *A. marina*, commonly known as grey mangrove or white mangrove, is a species of mangrove tree classified in the plant family Acanthaceae (formerly in the Verbenaceae or Avicenniaceae). As with other mangroves, it occurs in the intertidal zones of estuarine areas (Fatemeh et al. 2013). This species has high capacity for absorbing mercury from marine environment (Fatemeh et al. 2013; Almahasheer et al. 2014; Kholoud et al. 2017).

A. marina, commonly known as grey mangrove or white mangrove, is a species of mangrove tree classified in the plant family Acanthaceae that is distributed along the Persian Gulf (Fatemeh et al. 2013). There are very limited studies of estimating the concentrations of mercury in different mangrove plant parts from Persian Gulf. But, there are no clear reports on the concentration of mercury in different parts of *A. marina* from Emam Khomeini Port, south Iran (Fatemeh et al. 2013). Therefore, the study on mercury distribution and pollution are necessary in the different parts of the mangrove *A. marina*. The purpose of this study is to measure mercury concentrations sediment and different tissues (root, stem and leaf) of the mangrove *A. marina*. Also, the correlation between mercury in different tissues was studied.

MATERIALS AND METHODS

Emam Khomeini Port is an Iranian port in the Khuzestan shore, and is the largest port in south of the Iran (Fatemeh et al. 2013). This port is one of the main economic assets of the northwest coasts of the Persian Gulf serving a variety of industrial activities. Sediments and mangrove forest samples obtained from 4 samping sites including Petrochemical, Majideih, Jafari and Majideih in Emam Khomeini Port in the Khuzestan shore, south Iran and head of the Persian Gulf (Fig. 1).

Sediments samples were collected around the plant roots by a Van Veen Grab. Surface sediments (0–10 cm) were sectioned and stored in pre-combusted glass jars in a freezer (−20°C) until analysis. Before analysis, sediments were freeze-dried and ground to achieve homogeneity (MacFarlane et al. 2002; Murat et al. 2014).

The sieved sediment was powdered using an agate mortar and pestle. About 0.5 g of the powdered sample was placed in a Teflon beaker containing 10 ml aqua regia ($HNO3 + HCl$, 1:3 v/v). The mixture was heated until most of the liquid evaporated and allowed to cool before 5 ml of hydrogen fluoride (HF) were added. The samples were further cooled to room temperature for 1 h before being filtered (Dung Quang et al. 2017). The residue was filtered through a Whatman filter paper (No. 42) and diluted to 50 ml with distilled deionized water. For each digestion program, a blank was also prepared in the same manner as that employed for sediment samples with equal amounts of acid (Moopam 1999). The blank was also run at the same time. Blanks were used for correction of background and other sources of error (Zarei et al. 2014). Metal concentrations were determined by a ICP-AES (Keshavarz et al. 2012).

Plant sampling was collected from all stations by hand. The near 40 plant leaf was collected from all stations that their distance was about 1 meter from the ground. Between the all roots, the nutrient roots were sampling for analysis.

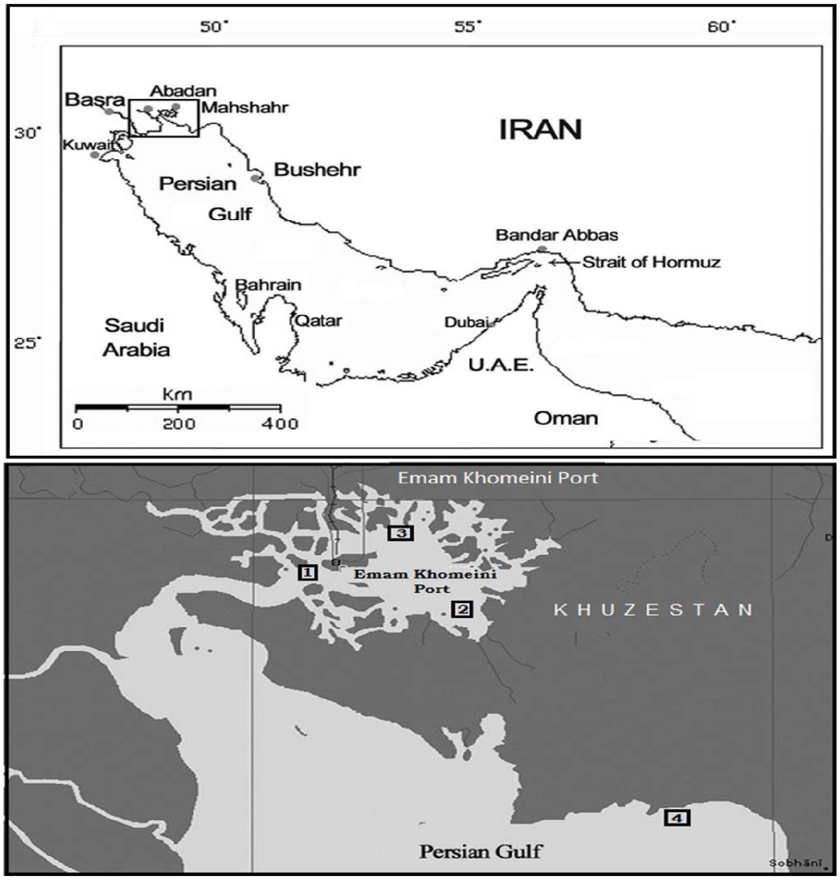

Figure. 1 Map of study area and sampling sites in along the Persian Gulf

The sampling of plant stem were collected by steel knife from the same of plant align in the all stations. Samples taken from all station stored in the polyethylene dishes after washing with sea water, and transported to the laboratory by ice room.

Plant tissues were washed with distilled water and kept in oven at 60˚c for 24 hours to dry (Oliveira et al. 2015). The dried tissues, next, were grinded using porcelain mortar and kept in refrigerator until the next steps. 3 repetitions of grinded tissue samples from every station were digested. 1g sample of every tissue from every station was mixed in a 10 ml mixture of concentrated nitric acid and hydrogen peroxide for 2 hours at 90˚c using the Hot plate. The digested samples, then, were cooled and diluted to the volume of 50 ml at laboratory temperature and filtered with 42 micron filter paper. Mercury concentrations were determined by a ICP-AES device (Murat et al. 2014).

All data were tested for normal distribution with Shapiro-wilk normality test. One-Way analysis of variance (ANOVA) fallowed by Duncan post hoc test was used to compare the data by station. T-test analyses was using for compare mercury between winter and summer. The metal concentration of each sample is expressed in micrograms of metal on gram dry weight (µg/g) and a probability of $p = 0.05$ was set to indicate statistical significance.

RESULTS AND DISCUSSION

Mean concentration of mercury in sediments collected from 4 sampling sites in winter and summer in Emam Khomeini Port, located in Khuzestan province, south Iran showed in Table 1. The mercury were ranged from 0.05 to 2.76 µg/g between all sampling sites, that minimum and maximum were in site 4 and 1, respectively. The mean concentration of mercury in different sampling sites in summer season were 1.69 ± 1.45 in site 1, 0.86 ± 0.05 in site 2, 0.60 ± 1.23 in site 3 and 0.16 ± 2.19 in sites 4, respectively. There was significant differences between diffident sampling sites ($P<0.05$), that highest concentration was in Petrochemical (1) estuary, followed by Majideih estuary (2), Jafari (3) estuary and Bardestan (4) estuary, respectively.

The mercury were ranged from 0.04 to 4.96 µg/g between all sampling sites, that minimum and maximum were in site 4 and 1, respectively. The mean concentration

Table 1 Range and mean concentration (SE) of mercury in sediments collected 4 sampling sites in winter and summer in Emam Khomeini Port

Season		Petrochemical (1)	Majideih (2)	Jafari (3)	Bardestan (4)
Summer	Range	0.34 – 2.76	0.13 – 1.82	0.09 – 1.26	0.05 – 0.62
	Mean	1.69 ± 1.45	0.86 ± 0.05	0.60 ± 1.23	0.16 ± 2.19
Winter	Range	0.82 – 4.96	0.39 – 2.25	0.15–1.46	0.04 – 0.48
	Mean	2.34 ± 0.49	1.10 ± 5.27	0.66 ± 0.25	0.17 ± 131

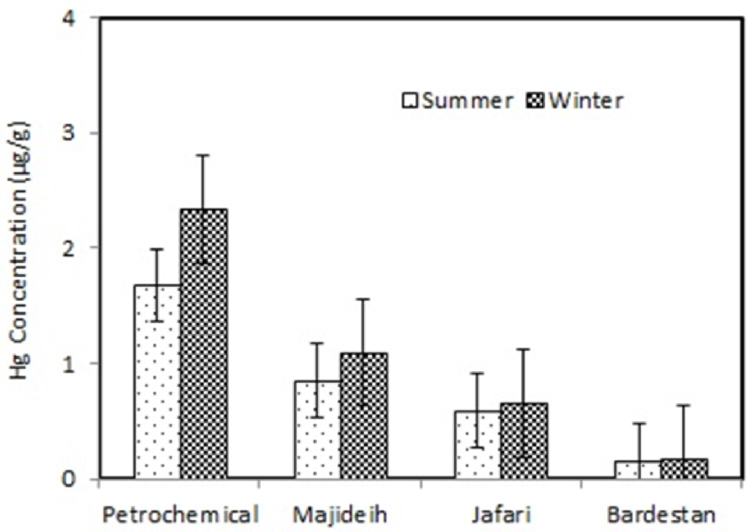

Figure 2 Comparison of Hg concentration in sediment from different estuaries between summer and winter

of mercury in different sampling sites in winter season were 2.34 ± 0.49 in site 1.10 ± 5.27 in site 2, 0.66 ± 0.25 in site 3 and 0.17 ± 131 in sites 4, respectively. There was significant differences between diffident sampling sites ($P<0.05$), that highest concentration was in Petrochemical (1) estuary, followed by Majideih estuary (2), Jafari (3) estuary and Bardestan (4) estuary, respectively.

Comparison of mercury concentration in sediment from different estuaries between summer and winter showed in Fig. 2. Results showed, there was significant differences between diffident seasons ($P<0.05$), and mercury concentration in sediment was higher in winter in compare the summer season. Mercury concentration in sediment depended on physicochemical parameters such as pH, temperature, salinity, organic carbon, carbonate, and other factor such as Hg sources in environment and industries activity (Einollahipeer et al. 2013; Dung et al. 2017). Almahasheer et al. (2014) reported on sediment around the mangrove forest *A. marina*, and showed metal concentration was higher in winter than other season, because industries activity are high and causes increase in metal production. In winter season, rain falling causes did wash of pollutants and it flood to estuaries environment (Shirvani Mahdavi et al. 2012).

Seedo et al. (2017) reported metal concentration in winter season was higher than other seasons, because increase in the sources pollutants activity causes increasing in the mercury concentration in collected from estuaries along the Emam Khomeinin Port. With decrease in the temperature, the absorbing level of mercury increasing, because the dissolved oxygen level increasing in the cool water. Also, organic carbon in sediment in cool season was high than other seasons, therefore, with increase in the organic carbon in sediment, they can made complex with meal and this complexes can be causes absorbing and accumulating of metal in sediments (Sumesh et al. 2017).

Al Anouti (2014) showed that pH value in environment around the sediments is low and in acidic conditions the mercury pollution is higher significantly than alkaline conditions. Usually in cold water based on sediments the pH value is low, there are negative correlation between pH

Table 2 Range and mean concentration (SE) of mercury in root tissue of mangrove forest species, *A. marina* collected 4 sampling sites in winter and summer in Emam Khomeini Port

Season		Petrochemical (1)	Majideih (2)	Jafari (3)	Bardestan (4)
Summer	Range	1.44 – 6.61	0.53 – 3.14	0.39 – 2.14	0.15 – 1.02
	Mean	3.26 ± 3.16	1.49 ± 0.75	0.87 ± 2.61	0.65 ± 4.05
Winter	Range	1.65 – 7.54	0.35 – 3.85	0.29–1.85	0.18 – 1.92
	Mean	4.13 ± 4.35	1.93 ± 2.31	0.94 ± 1.56	0.67 ± 0.24

value and metal concentration in sediments, therefore, in winter season the pH is low and metal concentration was high, therefore, pH is one of the important factors in metal concentration Dung et al. (2017) in a study showed there are significantly differences between different seasons and winter absorbing high metal concentration higher than other seasons (P<0.05), Generally, the higher mercury levels in winter were related to which coincides with high rainfall period and the most intense fishing activities, increase in the organic carbons, decrease in pH value and other environmental factors.

Mean concentration and the range of mercury in root tissue of mangrove forest species, *A. marina* collected from 4 sampling sites in winter and summer in Emam Khomeini Port showed in Table 2. In the summer, the mercury were ranged from 1.44 to 6.61 in site 1, o.53 to 3.14 in site 2, from 0.39 to 2.14 in site 2 and 0.15 to 1.02 in site 4, respectively. The mean concentration of mercury in summer season were 3.26 ± 3.16 in site 1, 1.49 ± 0.75 in site 2, 0.87 ± 2.61 in site 3 and 0.65 ± 4.05, respectively. There was significant differences between diffident sapling sites (P<0.05), highest concentration was in root of mangrove forest *A. marina* collected from site 1, followed by site 2, site 3 and site 4, respectively. The arrangement of mercury concentration in root of mangrove forest species, *A. marina* were as Petrochemical > Majideih > Jafari > Bardestan > or 1 > 2 > 3 > 4.

In general, the high concentrations of mercury in the Petrochemical (S1) sampling site indicate that higher exposure to these metals from the industrial effluences. There are many industrial units around this sampling site that causes increase pollutant to environment. But, number of pollutants sources such as industries was few around the other sampling sites, therefore, they receive low mercury concentration in compare to Petrochemical (S1).

In the winter season, the mercury were ranged from 1.65 to 7.54 in site 1 (Petrochemical), from 0.35 to 3.85 in site 2 (Majideih), 0.29 to 1.85 in site 3 (Jafari) and 0.18 to 1.92 in site 4 (Bardestan) (4), respectively. The mean concentration in winter was 4.13 ± 4.35 in site 1, 1.93 ± 2.31 in site 2, 0.94 ± 1.56 in site 3 and 0.67 ± 0.24 in site 4, respectively. The arrangement of mercury concentration in root of mangrove forest species, *A. marina* were as Petrochemical > Majideih > Jafari > Bardestan > or 1 > 2 > 3 > 4.

High metal concentration in wet seasons can be explained by the fact that the final destination of the contaminants carried away by rain and snow water is generally rivers. Besides, metals have a tendency to accumulate in sediment of aquatic systems and thus transport to mangrove forest species like *A. marine*. Heavy metal can be transport to different tissues of mangrove by root tissue, it means that metals in sediment absorbing by root and transport in stem and leaf. Therefore, mangrove forest species can be removal pollutants from aquatic environments.

Root is main tissue for absorbing pollutants from environment and it can absorb metals from sediments. There are significant differences between sediment and root of plant (P<0.05), and mercury concentration was higher in root tissue of plant than the sediments. The higher heavy metal concentration in roots than in the sediment may reflect the continuous accumulation and filtration of metals in roots over a long period of time. The high metal concentration in roots may also indicate high bioavailability of metals in the sediment (Usman et al. 2013).

In *Avicennia* species, air that is absorbed through aerial root lenticels can be transferred to the rhizosphere, oxidising the anaerobic sediment at the fine root level, reducing sulphide precipitation and lowering stability of iron plaque, thus allowing more metal exchange. In a study of metal accumulation in various sediments, Keshavarz et al. (2012) noted an increase in metal accumulation in roots in low pH sediments. Similarly, Abohassan (2013) noted increases in metal exchange under low pH and oxidize conditions which attract the metal ions to the negative charges of the sediment particles. Moreover, Hosseini et al. (2013) showed that the grain size in sediment is one of the important parameter that can governs metal binding and for hold and accumulate of metal between particles in sediments. In addition, the sediment physical properties also might influence metal accumulation.

In the winter, metal concentration is higher than other seasons, therefore, metal concentration in is high in sediments and in the tissues of mangrove forest. In winter

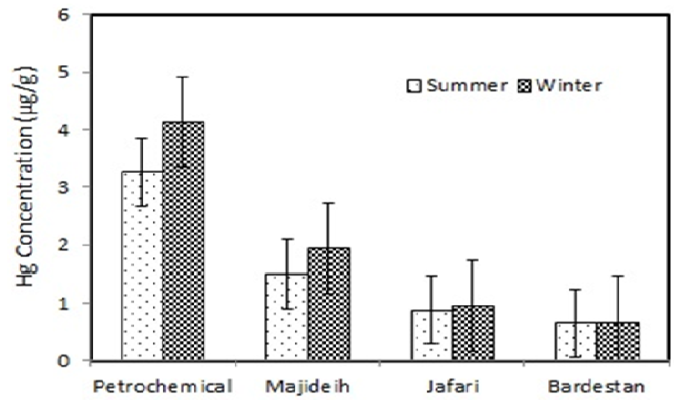

Figure. 3 Comparison of Hg concentration in root of mangrove forest, *A. marina* from different estuaries between summer and winter

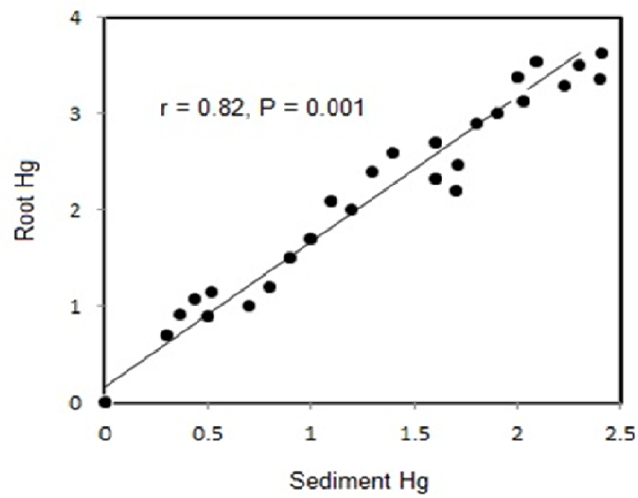

Figure. 4 Pearson correlation between Hg in sediment and root of *A. marina* in summer season

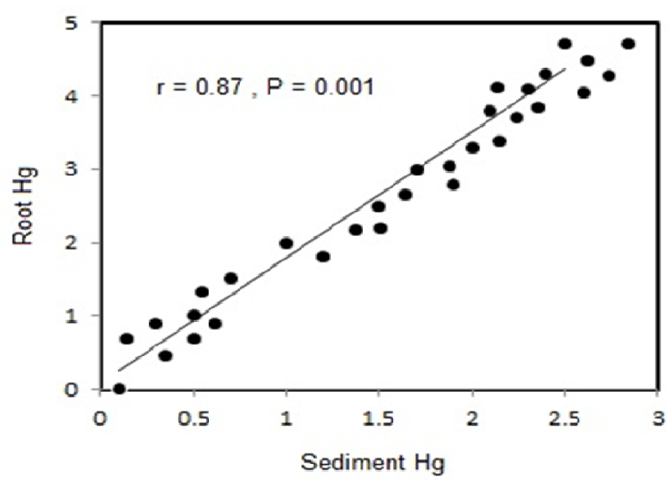

Figure. 5 Pearson correlation between Hg in sediment and root of *A. marina* in summer season

the temperature and pH value is low in compare to other seasons, there are negative correlation between metal concentrations with both factors, and with decrease in pH and temperature value, the ability of plant is increased for absorbing and removal metal from environment (Dung et al. 2017).

A reason another, in winter the water temperature is low, therefore, the mobility of metal ions in sediments is lower and they are more stabile in sediments, therefore, plant and mangrove forest can be easy absorb metals from sediments. Dung et al. (2017) report on mercury biomagnifications in the mangrove forest and showed mercury in tissues of mangrove in winter was higher than other seasons.

Edu et al. (2015) showed that mercury concentration in root of mangrove forest A. marine was higher in winter season than the other seasons, because in winter and wet season, sediments have high organic matter for made complex and hold of metal especially mercury. Also, Sumesh et al. (2017) suggested with present results and report organic matter is one of the most important in sediment for absorbing of heavy metal, because organic matter can be made a complex with metal in sediment that causes hold and keeping and finally accumulate of metal and transport to mangrove forest.

In general, pH, temperature, salinity and organic matter are important parameters in winter for increase of metals concentration in sediments and mangrove forest species. Many studied suggested with results of this study (Cyril et al. 2006; Shirvani Mahdavi et al. 2012; Einollahipeer et al. 2013; Chakraborty et al. 2013; Al Anouti 2014; Sumesh et al. 2017).

There are differences between tissues in mangrove forest for absorbing of pollutants, root, stem and leaf have different ability for absorbing and removal of pollutants. Root is the main and most important tissue for absorbing metal from sediment and play important role in removal of pollutants from aquatic environment. The type sediments around the root of plant are fine and soft such as clay and silt, therefore, they can accumulate high concentration of metals between particles, because fine particles has high value of organic matter, that it can absorbing metal in sediments by made complex.

The results of Pearson correlation showed there was high correlation between mercury in sediments and mercury concentration in root, and with increase of mercury in sediment the capacity of root increased for absorbing of mercury. The correlation value in winter and summer were ($r = 0.82$) and ($r = 0.87$), respectively. The correlation in both seasons was high, but in winter was higher than summer season. Therefore, there was high correlation between mercury concentration n sediment and root of *A. marina* in winter and summer season.

This study showed that the concentrations of mercury in the root tissues of mangrove plants were relatively higher than the concentrations in the sediments. Mercury can be highly toxic to plants, seriously affecting their growth; however, the exact mechanism of mercury translocation in plants remains uncertain. Therefore, mercury in sediments from four sampling sites located in Emam Khomein Port, north part of the Persian Gulf in Khuzestan coasts can be removal by phytoremediation technique, mangrove forest, Avicennia marina.

Phytoextraction, a kind of phytoremediation technique, requires effective translocation of pollutants from root to shoot to enable harvest and removable of contaminants. Phytoremediation refers to the technologies that use living plants to clean up soil, air, and water contaminated with hazardous contaminants. It is defined as the use of green plants and the associated microorganisms, along with proper soil amendments and agronomic techniques to either contain, remove or render toxic environmental contaminants harmless. Phytoremediation is a cost-effective plant-based approach of remediation that takes advantage of the ability of plants to concentrate elements and compounds from the environment and to metabolize various molecules in their tissues. It refers to the natural ability of certain plants called hyper accumulators to bioaccumulation, degrade, or render harmless contaminants in soils, water, or air. Toxic heavy metals and organic pollutants are the major targets for phytoremediation. Knowledge of the physiological and molecular mechanisms of phytoremediation began to emerge in recent years together with biological and engineering strategies designed to optimize and improve phytoremediation. In addition, several field trials confirmed the feasibility of using plants for environmental cleanup.

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